

CAPTURE

1. Developers

CAPTURE was developed by Watermark Numerical Computing, with support from Kataclima, Italy.

2. What CAPTURE Does

CAPTURE performs the following tasks based on equations that are presented in Bear and Jacobs (1965) and Kasenow (2010). These equations assume zero recharge, uniform aquifer properties and a non-zero hydraulic gradient.

- Calculates the infinite-time capture zone of an extraction well.
- Calculates travel times to the extraction well from points within this zone.
- Repeats these calculations for many stochastic realizations of:
 - hydraulic conductivity;
 - porosity;
 - groundwater gradient;
 - groundwater gradient direction.
- After performing these calculations, CAPTURE records probabilities, evaluated over a grid, that the travel time is less than a user-specified threshold in a number of different files.
- Optionally, CAPTURE records stochastic travel times at user-supplied observation points so that travel time histograms can be constructed at these points.

All CAPTURE outputs are recorded using real-world coordinates. Hence they can be overlain on maps and images of a study area.

3. CAPTURE Modes of Operation

CAPTURE can be run in either *deterministic* mode or *stochastic* mode.

When run in *deterministic* mode, CAPTURE obtains a single set of aquifer characteristics from the DET_PARAMETERS block of its input file. It then writes five output files. These are as follows:

- A SURFER BLN file defining the infinite-time capture zone boundary;
- A SURFER grid file that allows contouring of travel times to the extraction well from points within the capture zone;
- A MIF/MID file pair recording travel times to the extraction well; this can be imported into a GIS;
- A CSV file recording travel times; this can also be imported into a GIS.

The grid over which travel times are evaluated is specified in the GRID section of the CAPTURE input file. Points in this grid for which travel times are not computed (as they do not lie within the capture zone) are awarded a travel time value of 1.701410E+38 in the

SURFER grid file; this is SURFER's blanking value. They are awarded a value of -100.0 in the MIF/MID file pair that are written by CAPTURE. Non-captured points are omitted from the CAPTURE-produced CSV file.

If run in *stochastic* mode, CAPTURE generates random realizations of the following aquifer properties. Travel times are calculated for all of these realizations.

- hydraulic conductivity;
- porosity;
- hydraulic gradient;
- bearing of hydraulic gradient;
- aquifer thickness.

Hydraulic conductivity and porosity are assumed to be log-normally distributed while hydraulic gradient, the bearing of hydraulic gradient, and aquifer thickness are assumed to be uniformly distributed between user-supplied lower and upper bounds.

If run in *stochastic* mode, CAPTURE writes the following files:

- A SURFER grid file recording the probability that the travel time is less than a user-supplied threshold;
- A MIF/MID file pair recording this same information;
- A CSV file recording this same information; optionally points can be omitted from this file if the probability is below a user-specified level;
- A CSV file in which travel times are recorded for all realizations at a set of user-supplied observation points; randomly-realized values of aquifer characteristics are also recorded in this file.

4. The CAPTURE Input File

4.1 Overview

CAPTURE receives its instruction from a keyword-based input file. The input file is divided into blocks. Except for the OPTIONS block, blocks can be provided in any order. The OPTIONS block must precede all other blocks. Depending on its mode of operation (defined in the OPTIONS block), some blocks may be omitted from the CAPTURE input file. The contents of blocks which are not needed for CAPTURE's current mode are ignored.

An example of a CAPTURE input file is provided in Figure 1.

```

START OPTIONS
  MODE stochastic
END OPTIONS

START EXTRACTION
  XB      10000.0
  YB      20000.0
  RATE    500.0
END EXTRACTION

START DET_PARAMETERS
  K        8.0
  GRADIENT 0.01
  BEARING  30.0
  POROSITY 0.25
  THICKNESS 30.0
END DET_PARAMETERS

START STOCH_PARAMETERS
  K_MEAN      8.0
  K_LOGSIGMA  0.2
  POR_MEAN    0.25
  POR_LOGSIGMA 0.2
  GRAD_LOWER  0.005
  GRAD_UPPER   0.1
  BEARING_LOWER -60.0
  BEARING_UPPER 60.0
  THICKNESS_LOWER 25.0
  THICKNESS_UPPER 35.0
END STOCH_PARAMETERS

START STOCH_CONTROL
  REALIZATIONS 1000
  TIME_THRESHOLD 180.0
  RANDOM_SEED 1111
END STOCH_CONTROL

START GRID
  X0      9800.0
  Y0      19800.0
  DELTAX   2.0
  DELTAY   2.0
  NX       300
  NY       300
END GRID

START OBSERVATIONS
  obs1 10000.118 20016.598
  obs2 10016.598 20031.580
  obs3 9957.419 20078.025
END OBSERVATIONS

START OUTPUT
  BASENAME      cap
  PROBCSVTHRESH 0.0
END OUTPUT

```

Figure 1. Example CAPTURE input file.

Blocks within the CAPTURE input file are now discussed in detail.

Note that CAPTURE ceases execution with an appropriate message if any item of its input file is in error.

Note also that CAPTURE assumes no units. It is the user's responsibility to ensure that units are consistent.

4.2 OPTIONS Block

The OPTIONS block must be the first block in the CAPTURE input file. It must contain a single keyword, this being *mode*. CAPTURE's mode must be declared as either *deterministic* or *stochastic*.

4.3 EXTRACTION Block

The EXTRACTION block is mandatory. Extraction well details are supplied through this block. The real-world coordinates of the extraction well are supplied following the *xb* and *yb* keywords. The extraction rate is provided following the *rate* keyword.

4.4 DET_PARAMETERS Block

This block can be omitted from the CAPTURE input file if CAPTURE is run in *stochastic* mode. It is used to provide the values of aquifer characteristics that are employed when CAPTURE is run in *deterministic* mode.

Required aquifer characteristics are obvious from the keywords that are featured in this block. Note that *k* is hydraulic conductivity and *gradient* is hydraulic gradient. *Bearing* is measured clockwise from north.

4.5 STOCH_PARAMETERS Block

This block can be omitted if CAPTURE is not run in *stochastic* mode. It contains parameters on which stochastic realizations of aquifer properties are based.

The mean values of hydraulic conductivity and porosity should be provided following the *k_mean* and *por_mean* keywords. Note that both of these quantities are assumed to be logarithmically distributed. Values provided for *k_mean* and *por_mean* should be the antilogs of the log means; as such, they are not actually equal to the linear means of hydraulic conductivity and porosity. However these values are more convenient to provide than the log means of these quantities.

The same does not apply to the standard deviations of hydraulic conductivity and porosity. The standard deviations of the logs (to base 10) of these quantities should be provided following the *k_logsigma* and *por_logsigma* keywords. As stated above, hydraulic conductivity and porosity are assumed to possess log-normal distributions.

Hydraulic gradient, the bearing of hydraulic gradient, and the aquifer thickness are all assumed to possess uniform distributions. The lower and upper bounds of these distributions should be provided in response to pertinent keywords that appear in the STOCH_PARAMETERS block.

4.6 STOCH_CONTROL Block

Variables which control stochastic analysis should be provided through the STOCH_CONTROL block. The number of realizations should follow the *realizations* keyword. The random number seed (a positive integer) should follow the *random_seed* keyword. This keyword is optional. If a CAPTURE input file omits this keyword, CAPTURE provides its own random seed.

When run in *stochastic* mode, CAPTURE computes the probability that the capture zone is less than a certain, user-supplied time. This time is provided following the *time_threshold* keyword.

The *stoch_control* block can be omitted if CAPTURE is run in *deterministic* mode.

4.7 GRID Block

The outcomes of most of CAPTURE's calculations, whether run in *deterministic* or *stochastic* mode, populate a model grid. The specifications of this grid are provided in the GRID block.

The grid comprises $nx \times ny$ points. The x direction is east while the y direction is north. The distance between points is $deltax$ in the x direction and $deltay$ in the y direction. The coordinates of the point that occupies the south-west corner of the grid are $(x0, y0)$. This point has the lowest x coordinate and the lowest y coordinate of any grid point.

4.8 OBSERVATIONS Block

The OBSERVATIONS block is not used if CAPTURE is run in *deterministic* mode. It is optional if CAPTURE is run in *stochastic* mode.

The OBSERVATIONS block can contain the names and coordinates of up to 10 observation locations. Each observation name must be 20 characters or less in length.

On each occasion that CAPTURE generates a set of aquifer properties, it records these properties in a CSV file. If observations are provided, travel times from observation points to the extraction well are recorded in the final column of this CSV file.

4.9 OUTPUT Block

All files that are written by CAPTURE start with the same text string. This string must be provided following the *basename* keyword. Suppose that this string is supplied as “case”. Files written by CAPTURE if run in *deterministic* mode are then as follows.

Filename	Contents
<i>case_long_term_capture_boundary.blm</i>	A SURFER BLN file outlining the infinite-time capture zone boundary.
<i>case_travel_times.grd</i>	A SURFER grid file containing travel times to the extraction well. A blanking value of 1.701410E+38 designates grid points for which water is not captured by the extraction well.
<i>case_travel_times.mif</i> <i>case_travel_times.mid</i>	A MIF/MID file pair providing travel times to the extraction well. A value of -100.0 designates grid points for which water is not captured by the extraction well. These files can be imported into any GIS.
<i>case_travel_times.csv</i>	A CSV file containing grid point coordinates and travel times to the extraction well. Points outside the capture zone are omitted from this file.

Table 1. Files written by CAPTURE when run in *deterministic* mode.

Filename	Contents
<i>case_probability_below_time_thresh.grd</i>	A SURFER grid file containing the probability that the travel time to the extraction well is less than the time supplied with the <i>time_thresh</i> keyword.
<i>case_probability_below_time_thresh.mif</i> <i>case_probability_below_time_thresh.mid</i>	A MIF/MID file pair containing this same information. These files can be imported into any GIS
<i>case_probability_below_time_thresh.csv</i>	A CSV file containing the <i>x</i> and <i>y</i> coordinates of grid points together with probabilities that the travel time to the extraction well is less than the time supplied with the <i>time_thresh</i> keyword. Points with probabilities below <i>probcsvthresh</i> are omitted from this file. If <i>probcsvthresh</i> is omitted from the OUTPUT block, then probabilities at or below zero are omitted from this file.
<i>case_pars_and_obs.csv</i>	A CSV file containing random values of aquifer properties used in calculation of probabilities that appear in the above files. If the CAPTURE input file contains an OBSERVATIONS block, travel times from each observation point to the extraction well are recorded for each realization of aquifer properties.

Table 2. Files written by CAPTURE when run in *stochastic* mode.

Note the role of the *probcsvthresh* keyword in the above table.

5. Pictures

Figure 2 shows probabilities that travel time is less than a user-prescribed threshold, with redder colours indicating greater probabilities. These were computed by running CAPTURE in *stochastic* mode. The white line shows the infinite-time capture zone boundary for mean aquifer properties. This was computed by running CAPTURE in *deterministic* mode.

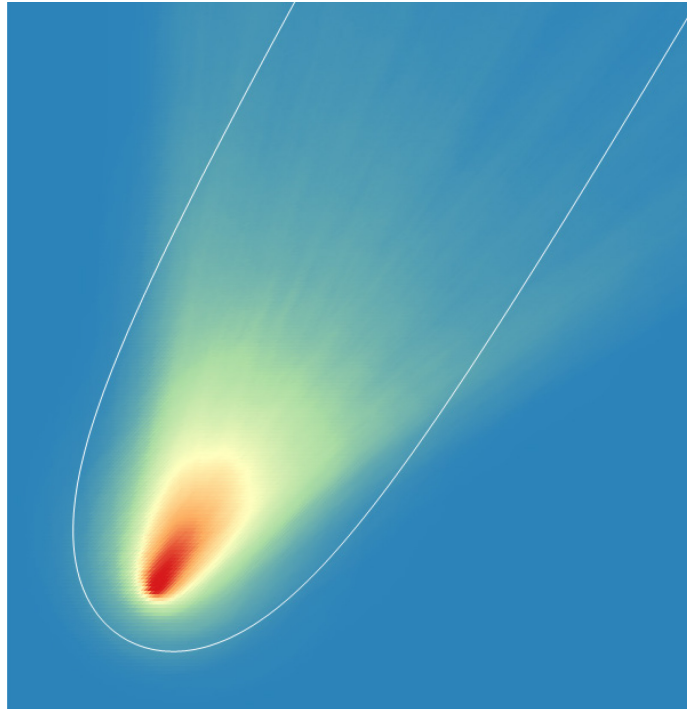


Figure 2. Capture probabilities and the infinite-time capture boundary.

Figure 3 displays CAPTURE-calculated probabilities of below-threshold travel time superimposed on an image in a GIS.



Figure 3. CAPTURE-calculated probabilities superimposed on an image.

6. References

Bear, J. and Jacobs, M., 1965. On the movement of water bodies injected into aquifers. *Journal of Hydrology* 3:37-57.

Kasenow, M., 2010. Applied Ground-Water Hydrology and Well Hydraulics. Water Resources Publications. Third Edition.